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Reconstruction of passenger carriage floor

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Abstract Better acoustic solution can be detected not just experimentally, but also by computing and choosing adequate tools for the simulation of selected physical process. Simulation can detect the acoustic properties of materials used in the design of vehicles. Acquired information on the behaviour of different acoustic materials can consequently be used in the design of sound resistant structures of railway vehicles.

Key words Noise, Stered, Mineral wool, Passenger carriage

1. INTRODUCTION

Nowadays we concentrate attention to the design, but also to the modification, modernization and reconstruction of transport to a wide spectrum of operating parameters. One of the important parameters, which dominate in the selection of a suitable vehicle, is comfort. Word comfort very often introduces silence. Rate of noise level which is generated in the interior of a vehicle is also a rate of quality evaluation of a construction. Attention is paid to reducing noise in interior of vehicles, which is radiated through structure of floor, in the railway traffic.

2. ANALYSIS

In the modernization of rail vehicles there is not often any change of shape and dimensional parameters of construction, but particularly in the use of new materials. At the present, in the construction of the floor of passenger carriage series Bdghmeer as thermal and sound insulation is used a "technical insulation mineral wool LFM 5 Alu R from company Knauf Insulation".

Figure 1. Passenger carriage of series Bdghmeer (http://www.bahnbilder.de/, 2014)

Mineral and rock wool have in comparison with more modern thermal and sound insulations many disadvantages. It is dangerous to health, material having a low elasticity which lost over time. It is coming to ageing and loss volume and drastically losing heat-insulating properties. (Trevor J. Cox, 2009) Modernization of the floor includes fully dismantling of individual layers except the trapezoidal sheet having a support function. From trapezoidal steel sheet old paint is removed and new glaze is applied. The structure of layer is maintained. Old materials are replaced with new materials.
In the modernization of the passenger carriage floor no change will occur in the shape and dimensions of the structure and no change will occur in the use of new types of materials. There is only restoring the properties of the materials from which the floor is made. When we want maintain shape and dimensions of the structures and improve ride comfort, we must use new types of acoustical materials.
Possible solution can be material STERED®, which is novelty on the market of thermal and sound insulation material. STERED® used in the construction of the floor is suitable solution, because has excellent acoustic properties.

Figure 2. Textile material originally used in the automotive industry, which is recycled and used for production of STERED® (http://www.stered.sk, 2014)

The input material consists from textile parts waste of new cars, but also from separated textile parts of cars after end of life. Separation of textile material produces significant volumes of textile materials of specific qualities. This material is characterized by:

- Excellent properties that are not changed in time.
- Material was originally used in the cars and was determined to sound and thermal insulation while must meet the criteria of strict requirements especially for health and safety.

To define the behaviour of new sound-insulating material STERED® in the floor construction of the passenger carriage, it is important to perform a computer simulations, which proves the expected acoustic effect in operating conditions. (http://www.stered.sk, 2014)

3. SIMULATION OF SOUND PRESSURE TRANSFER THROUGH CONSTRUCTION OF FLOOR

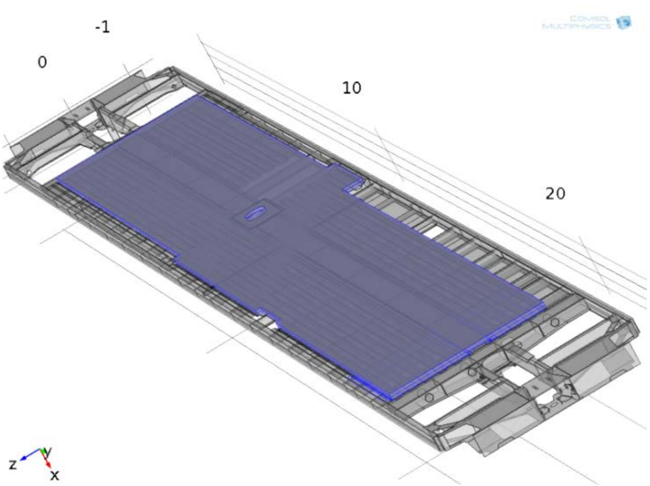

Figure 3. The floor construction of the passenger carriage series Bdghmeer created in CATIA R5V21 and imported into COMSOL Multiphysics 4.4

For simulation of the sound pressure transfer through floor construction of the passenger carriage series Bdghmeer was chosen as an appropriate tool program COMSOL Multiphysics 4.4. The aim of the simulation is to implement frequency analysis and detect any differences between the attenuation spectrums of the used materials.

3.1 Poroacoustics

The program COMSOL Multiphysics offers an important function "poroacoustics". By using this function we can add extended spectrum of parameters to a material and it can be considered as a porous media. The sound doesn´t spread only through the fibres of material, but as well as through the fluid medium which is in pores among the fibres. This medium is usually air. (Havelock D., 2008) In this case, the Johnson-Champoux-Allard model was used. The Johnson-Champoux-Allard model is an equivalent fluid model that mimics two limiting behaviours of the full poroelastic material model defined by Biot's theory. The first is the rigid porous matrix model (equation 1) and the second is the limp porous matrix model (equation 3). An equivalent fluid model is computationally less demanding than the full poroelastic model. However, they are only physical correct for certain choices of material parameters. Both models are based on describing the frequency dependent, effective density $\rho_{(\omega)}$ and the effective bulk modulus $K_{(\omega)}$ of the saturating fluid inside the porous matrix. The following parameters used in the (Equation 2) are given in (Table 1) have decisive effect on the acoustic properties of investigated materials. These parameters were used in the simulation, and are acquired from the manufacturers of materials. The parameters were acquired in a laboratory of the manufacturer in accordance with the relevant standards.

Equation 1

$$\rho_{rig} = \frac{\tau\rho_f}{\varepsilon_p}\left[1 + \frac{R_f\varepsilon_p}{i\omega\rho_f\tau}\sqrt{1 + \frac{4i\omega\tau^2\mu\rho_f}{R_f^2 {L_v}^2 {\varepsilon_p}^2}}\right]$$

Equation 2

$$K_{eq} = \frac{\gamma P_o}{\varepsilon_p}\left[\gamma - (\gamma - 1)\left(1 + \frac{8\mu}{i\omega {L_{th}}^2 P_r \rho_f}\sqrt{1 + \frac{i\omega {L_{th}}^2 P_r \rho_f}{16\mu}}\right)^{-1}\right]^{-1}$$

Equation 3

$$\rho_{limp} = \frac{\rho_{rig}\rho_{av} - {\rho_f}^2}{\rho_{av} + \rho_{rig} - 2\rho_f}$$

Equation 4

$$\rho_{av} = \rho_d + \varepsilon_p\rho_f$$

Equation 5

$$L_v = \frac{1}{s}\sqrt{\frac{8\mu\tau}{\varepsilon_p R_f}}$$

Equation 6

$$L_{th} = \frac{2V_p}{S_p} \approx 2L_v$$

Table 1: Material parameters

Value	Symbol	Units	Mineral wool	STERED® ID
Flow resistance	R_f	[kPa.s/m²]	5	5÷100
Thermal characteristic length	L_{th}	[m]	650.10^{-6}	205.10^{-6}
Viscous characteristics length	L_v	[m]	420.10^{-6}	97.10^{-6}
Fluid Density	ρ_f	[kg/m³]	1.204	1.204
Dynamic viscosity for air	μ	[Pa.s]	$1.818.10^{-5}$	$1.818.10^{-5}$
Speed of sound in air	c	[m.s⁻¹]	343	343
Thermal conductivity	k	[W/(m.K)]	0,04	0,054
Porosity	ε_p	1	0.95	0.99
Tortuosity	τ	1	1,03	1,38
Absolute pressure	P_o	[atm]	1	1
Prandtl number	P_r	1	1	1
Porous material density	ρ_d	[kg/m³]	50	200

Figure 4. Mineral wool Knauf insulation LMF 5 Alu R and STERED® (http://www.knaufinsulation.sk, 2014) (http://www.stered.sk, 2014)

The surface of trapezoidal steel sheet is exposed to acoustic pressure of 20 Pa (120 dB). The frequency range of this sound is from 5 Hz to 20 kHz, with step 5 Hz. During the simulation, it is possible to monitor the transfer acoustic pressure through construction into interior in this spectrum. The aim is to find a material with a better

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attenuation ability of low-frequency sounds than mineral wool. Attenuation can be determined by comparing the measured frequency analysis in individual layers of floor construction and in interior of the passenger carriage, both in the current condition as well as when the material STERED® is used. This can be achieved by interesting "Point graph" function, where it is possible in the individual points (Figure. 5) to record the sound pressure depending on the excitation frequency. For simulation wasn´t used 3D model, because it is very complicated, but a simplified cross-sectional of construction in 2D was used.

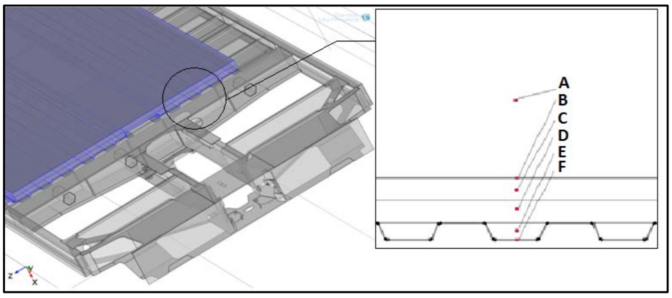
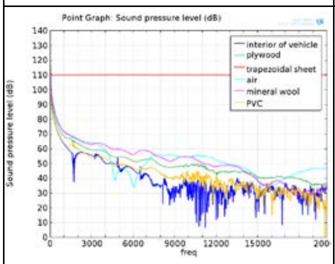
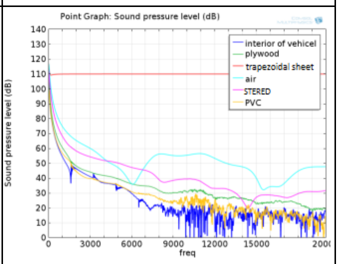
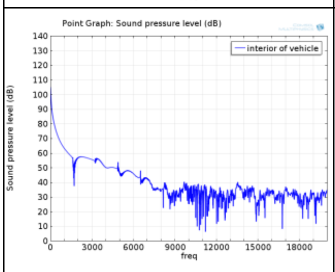
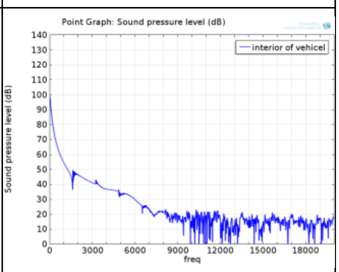


Figure 5. Measured points, which is located in layers of floor. A- interior of passenger carriage, B – PVC, C – plywood, D – STERED/Mineral wool, E – Air, F – Trapezoidal steel sheet

4. RESAULTS OF SIMULATION

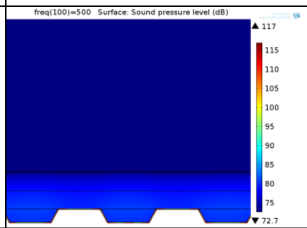
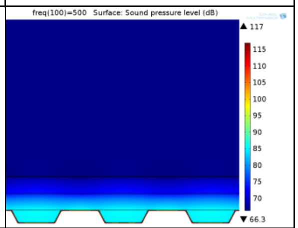
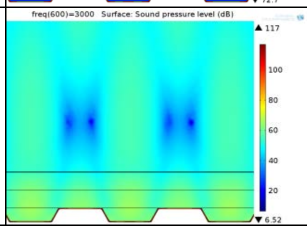
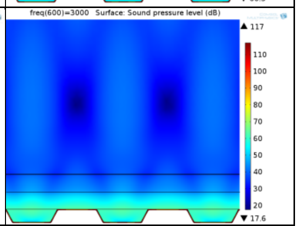
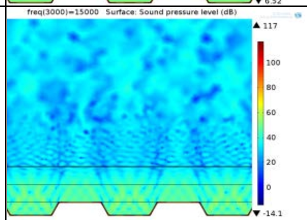
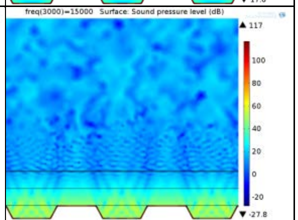
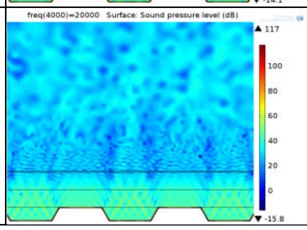
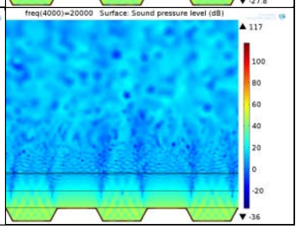
Table 2: Frequency analysis record in measured points

MINERAL WOOL	STERED®
	
	

5. CONCLUSION

- By using "poroacoustic" function in COMSOL Multiphysics the initial noise, which is generated by bogie of passenger carriage and transfers through the floor, was simulated.
- Results of simulations are shown in the frequency spectrum of noise, which is transferred through the floor in different points of the floor construction.
- It was detected that results of the simulation depend on the choice of input conditions, the acoustic properties of the passenger carriage floor and the material properties of the porous material in the floor. Other possibilities of verification of expected acoustic properties of the selected insulating material will continue.
- The dependencies of sound reduction of used material for the selected frequencies of noise generated by bogie are shown. From these initial simulations the expected sound-insulating properties of selected materials can be observed.
- We assume that in the consequent research the simulation conditions will be made more precise as well as the statistical analysis and complex evaluation of continuous results of simulation in order to perform the verification of experiments in real service on railways will be done.

Table 3: Results of simulation

f [kHz]	MINERAL WOOL	STERED®
0.5		
3		
15		
20		

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